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REVIEW PAPER

Integrated Enhanced and Synthetic Vision System for Transport Aircraft

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ABSTRACT

A new avionics concept called integrated enhanced and synthetic vision system (IESVS) is being developed to enable flight operations during adverse weather/visibility conditions even in non precision airfields. This paper presents the latest trends in IESVS, design concept of the system and the work being carried out at National Aerospace Laboratories, Bangalore towards indigenous development of the same for transport aircraft.

Keywords: Enhanced vision system, synthetic vision system, image fusion

1. INTRODUCTION

In order to accommodate the increasing air transportation demands in a safe, efficient and reliable manner, equivalent visual operations (EVO) is envisioned as the concept for the next generation air transportation system. EVO helps to achieve the safety and pace of the existing visual flight rules (VFR) operations irrespective of the weather and visibility conditions[1]. The instrument landing system (ILS) is currently the predominant navigation aid to enable low-visibility/ceiling approach and take-off operations. But it is very expensive and economically not feasible to provide ILS at all airports. To minimize the cost, aircraft-based technologies are being envisaged to provide EVO capability. Synthetic vision system (SVS) and enhanced vision system (EVS) or a combination of the two known as integrated enhanced and synthetic vision system (IESVS) as well as global position system (GPS) with augmentation system are the key technologies being considered. These new aircraft-based enhanced flight vision data in combination with an accurate airport database will allow greater access and throughput at airports that would otherwise be unavailable due to insufficient ground infrastructure.

Reduced visibility and reduced situational awareness are the main cause for accidents during controlled flight into terrain (CFIT)[2] and IESVS is the suggested technology to bring down such accidents[3]. National Research Council (NRC) report on 'decadal survey of civil aeronautics'[4] lists SVS and EVS as one of the top fifty research and technology challenges for NASA in the next decade. NASA and many other leading avionic research teams world over are currently involved in research, development, testing, certification, and commercialization of IESVS[5-12].

Numerous analytical, simulator and flight test studies comparing IESVS to conventional displays have documented the potential of IESVS displays for providing improved aviation safety, enhanced pilot vehicle performance, and increased operational capacity[13-19].

2. INTEGRATED ENHANCED AND SYNTHETIC VISION SYSTEM

Integrated enhanced and synthetic vision system (IESVS) is functionally a combination of EVS and SVS. EVS generates the images in real time from combination of weather penetrating multispectral infrared (IR) imaging sensors like short wave infrared (SWIR), medium wave infrared (MWIR), long wave infrared (LWIR) and millimeter wave radar (MMWR). SVS generates a rendered image of the external scene topography from the perspective of the flight deck derived from aircraft attitude and high precision navigation data using onboard database of terrain, obstacles and relevant cultural features[2]. In principle, SVS generated from high precision onboard terrain database is sufficient to enable the pilot to land the aircraft under all weather conditions. However, under low visibility conditions there is no way the pilot can verify whether this information is correct, or if there are errors in either the navigation data or in the airport database. For the high precision tasks of approach and landing, very high integrity of airport databases and navigation data derived from on-board sensors has to be guaranteed[2]. Further, GPS could be unavailable due to jamming effects or the database could be inaccurate and may not include obstacles and incursions. Hence, the weather penetrating imaging sensors are used to extract significant structures like the runway and other obstacles in real time to provide separate thread integrity monitor and provide 'enhanced vision' to the pilot. The concept of IESVS[2,20] is illustrated in Fig. 1.

3. IESVS COMPONENTS

The IESVS is conceived to be a system of sensors, databases, computers, displays, and controls that will present visual representations of the environment outside the cockpit. Figure 2 shows the subsystem components of IESVS and other supporting avionic systems required for full functionalities/operational capabilities.

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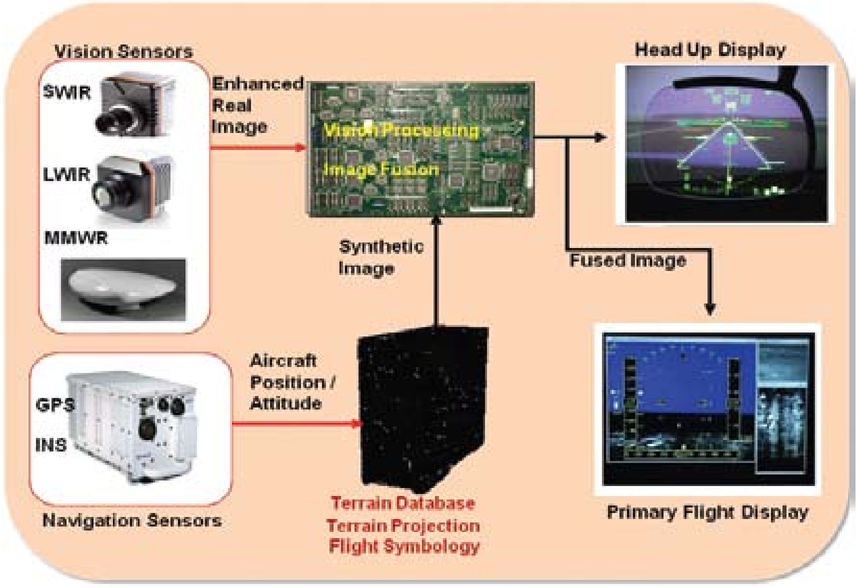

Figure 1. IESVS concept.

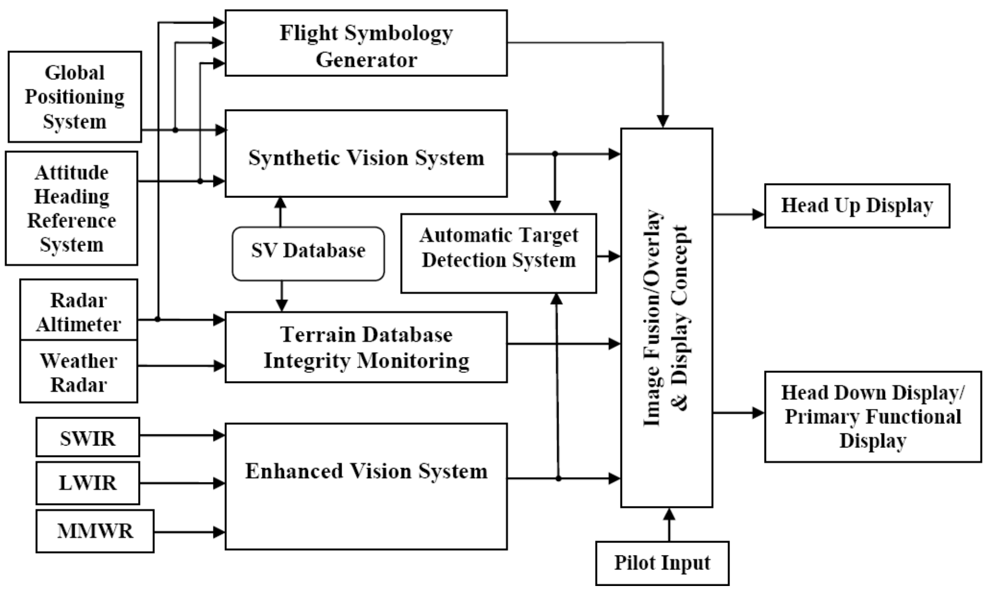

Figure 2. IESVS Subsystem components with other avionic systems.

4. DESIGN/IMPLEMENTATION ASPECTS

Design aspect of some of the key system components recommended by the NASA[21] and other research teams and the technologies available from avionics companies is presented below:

4.1 Enhanced Vision System Sensors

The enhanced vision system (EVS) is designed to provide improved visibility of the outside environment in real time during night and adverse atmospheric conditions such as fog, rain, haze, dust, or smog. The EVS system will be equipped with multispectral infrared (IR) sensors which sense the runway lights and other important runway features and millimeter wave radar (MMWR) which is an active sensor used for runway obstacle detection. Three types of infrared sensors working in three different infrared bands are commercially available for EVS applications[22-24].

Notwithstanding the high sensitivities that are now available, IR- based EVS is no solution for moderate to heavy fog and rain, and the natural choice to complement the IR sensors is MMW system. The MMW penetrates fog/rain quite well, but with limited resolution; an image-fusion system needs to be used to produce the composite image. With ongoing research, imaging MMW systems continues to progress in performance, physical size, and cost. MMWR working at 35 GHz or 94 GHz can be used for EVS applications[25,26].

4.2 Synthetic Vision System Elements

Main synthetic vision system (SVS) elements consist of terrain database and image generating engine (hardware/ software to render SV image). The digital elevation model (DEM) resolution is one factor that determines how well the SVS terrain depiction will match the actual terrain environment. NASA for its SVS applications has used 1 and

3 arc-s DEMs for approach, landing, and take-off/departure operations[27]. The most critical part affecting the accuracy and reliability of SVS is quality of terrain database used as it could lead to 'hazardously misleading information (HMTI)'. Thus, there is a definite requirement of some mechanism to monitor terrain database in real-time using other instruments on-board the aircraft. The required level of terrain database integrity depends upon the SVS application (whether advisory or flight critical) and the importance of the terrain database within the application. To mitigate potential risk of HMTI, NASA's best practices recommends the use of active database integrity monitoring equipment (DIME) like radar altimeter/millimeter wave radars[21].

4.3 Flight Displays

Flight displays play crucial role in effective implementation of IESVS concepts. The information provided on the displays should integrate tactical and strategic information necessary for flight operations as well as surface operations, including the runway incursion prevention along with the information from SVS and EVS. The IESVS displays could be presented on any one of head-up-display (HUD), head-down-display (HDD) or primary functional display (PFD), navigational display (ND) and synthetic vision auxiliary display (SV-AD). Display analysis and design should include the full range of performance parameters such as field of view (FOV), luminance, contrast, and resolution, etc. to generate matrices of performance against environmental conditions. Human factors evaluations must be integrated with evaluations of display approaches and technologies.

5. INDIGENOUS IESVS

Multi Sensor Data Fusion (MSDF) group at CSIR-NAL, has embarked on developing an indigenous IESVS and integrating it to the avionics suite of Indian transport aircraft. Indigenous IESVS is expected to provide aircraft the capability of operation from all Indian regional airports with minimal infrastructure and instrumentation facility under adverse weather conditions including day, night, rain, fog, smoke and other low visibility conditions. The GPS aided geo augmented navigation (GAGAN) program of the airport authority of India and ISRO likely to get into operation by the year 2014 is expected to provide CATI landing capabilities at all airports within India. With IESVS it is expected to achieve CAT II and possibly CAT IIIa approach and landing without any additional infrastructure facilities at most of the Indian airports. As part of the initial work, technology analysis, requirement specification was carried out and a roadmap for the technology development has been evolved. Following is a description of the prototype development and testing that was carried out at CSIR-NAL.

5.1 EVS Prototype Development and Testing

A scaled down version of the EVS prototype hardware with 8-12 μm long wave infrared (LWIR) sensor and electro-optic (EO) colour camera was designed and developed. The prototype EVS unit was field tested on a ground vehicle at HAL airport runway for collecting data to study issues related to sensor latency and FOV in addition to generating data for evaluation of different sensor/image fusion algorithms. Fig. 3 shows the EVS prototype experimental setup and Fig. 4 shows the EVS prototype unit mounted on test vehicle.

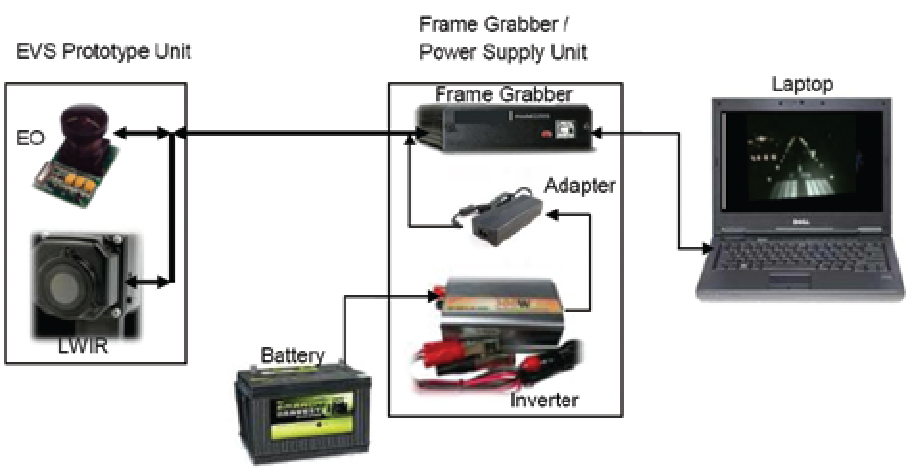

Figure 3. EVS prototype experimental setup.

Figure 4. EVS Prototype unit on ground test vehicle.

Experiments were conducted at HAL airport runway both during day time and after sunset. During both the days, test vehicle with the EVS unit mounted was made to traverse the run way from one end to the other. During the run, video was captured from both the cameras and recorded on the laptop which was subsequently anlayzed. For evaluation of the sensor characteristics across different lighting conditions during day and night, the EVS prototype unit was mounted on the National Flight Test Center (NFTC) tower at HAL airport to capture the images of aircraft landing, takeoff, and taxing at HAL airport and data was collected over a period of two weeks. The data gathered was also used to evaluate the image fusion algorithms developed in-house and for obstacle detection from the images.

5.2 Image Enhancement, Registration and Fusion for EVS

Generally the display devices in aircraft cockpit are of low dynamic range, but vision sensors used in EVS acquire high dynamic range (HDR) images. When attempting to display such HDR images in low dynamic devices, the low intensity areas are underexposed and appear black, and high intensity areas are overexposed and cannot be seen. To overcome this problem, histogram equalization (HE), and RETINEX algorithms[28] have been implemented and applied to the data collected by field tests.

The images acquired by multiple vision sensors have to be fused to produce single image to display on HUD or HDD. Before combining/fusing, the images from different sensors are required to be registered for their alignment orientation. Image registration algorithm using the point-mapping procedure has been implemented. Using point-mapping technique, number of control point pairs are selected from both reference and input images. Using these control point pairs, affine transform is computed which is applied on input image in order to align this image with reference image. For fusing the registered LWIR and EO image/video pixel level fusion technique, wavelet transform (WT) and laplacian pyramid (LP) algorithms have been developed and evaluated[29,30]. WT and LP algorithms are selected for fusing images/video of EVS as they are computationally very simple and are suitable for real time applications. In these algorithms image/video fusion is performed by decomposing the images. The performance of these fusion algorithms are evaluated in terms of root mean square error (RMSE), peak signal to noise ratio (PSNR), spatial frequency and standard deviation. The fusion quality evaluation metrics are shown in Table 1. It is observed that fusion with higher levels of decomposition would provide better results, but requires higher computation time. Therefore, level of decomposition should be based on performance requirement and application. Wavelet-based image fusion algorithms provides slightly better results based on the objective evaluation metrics shown in Table 1. Subjective evaluation of these algorithms will be carried out to select the better image fusion algorithm.

Figs. 5 and 6 show the images recorded by EO and LWIR cameras and the fused image during day time and after sunset with runway lights 'ON'. It can be observed from these images that only runway lights are visible in EO image and not the other features of the runway, whereas in LWIR image runway markings are clearly visible and not the runway lights. When both the images are fused with proper image registration, the fused image contains all the necessary information of the runway for better situational awareness to the pilot.

In these experiments, along with EO and LWIR, GPS receiver was used to record camera position and correction using the GPS ground station facility available at Airforce System Testing Establishment (ASTE), Bangalore was applied to GPS data to generate accurate differential GPS (DGPS) position

Table 1. Image fusion quality evaluation metrics

		Fusion quality evaluation metrics				
		RMS error	Peak SNR	Spatial frequency	Standard deviation	Execution time (s)
Fusion algorithm	LP^1	9.0467	38.600	12.490	46.111	0.5289
	LP^2	7.7387	39.278	15.526	46.834	0.5643
	WT^1	8.835	38.703	13.084	46.232	0.4158
	WT^2	7.466	39.434	15.695	46.994	0.4454

Note: ^{1} and ^{2} indicates level of decomposition

Figure 5. Image of HAL runway taken at day time.

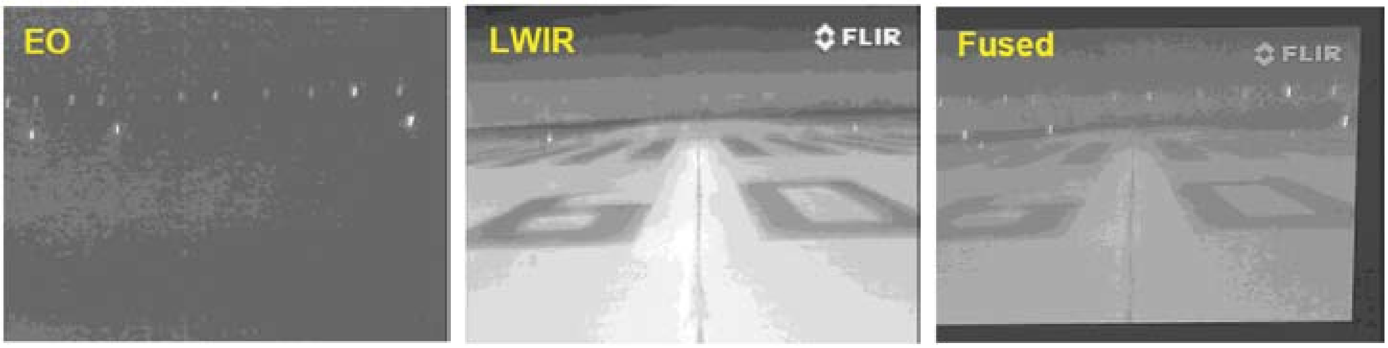

Figure 6. Images of HAL runway taken after sunset with runway lights.

data. The GPS heading was also recorded and the position and heading data subsequently used for rendering synthetic runway data from the synthetic terrain data base which includes SRTM DTED level 1 database of the HAL airport integrated in the distributed engineer in the loop simulator (DELS) at NAL. The GPS data in WGS84 coordinate system was transformed to local ENV frame (East, North and Vertical w.r.t database) for rendering the terrain data. Fig. 7 shows the images captured by EO and LWIR cameras, the fused image data after registration and the corresponding synthetic images retrieved from DELS using recorded camera position data from GPS.

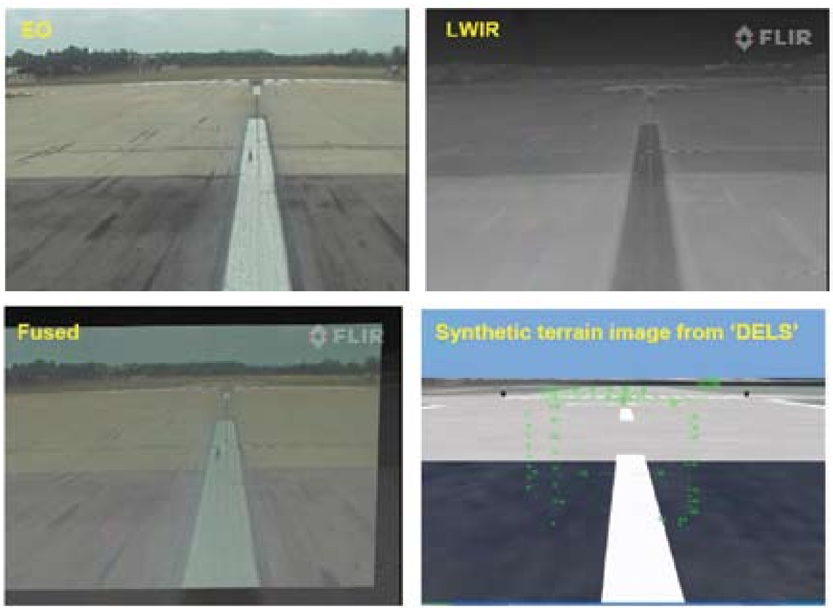

Figure 7. Recorded EO/LWIR, fused and corresponding synthetic image.

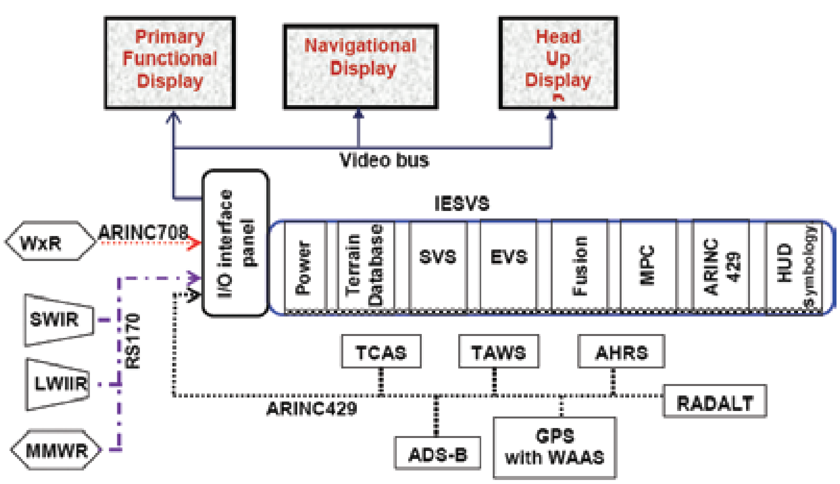

Figure 8. Planned integration of IESVS with IMA.

5.3 Database Integrity Check

NAL team has developed terrain database integrity monitoring strategies using downward looking (DWL) sensors and forward looking (FWL) sensors. DWL sensor (Radar Altimeter) based approach is straight forward and requires minimum retrofit of existing aircrafts whereas FWL sensor (Weather Radar) based approach is statistically more complex and may require installation or modification of sensors onboard the aircraft. The advantage of using FWL sensor is that it alerts the pilot much in advance as it can see the terrain ahead of aircraft. DWL sensor based terrain integrity check algorithm has been validated using radar altimeter and GPS data of a high performance fighter aircraft obtained from various flight trials done at different geographical locations in India[31].

5.4 Flight Simulator and Avionics Integration plans for IESVS development and testing

Development and testing of IESVS is planned with coordinated use of various techniques like component tests in laboratory; hardware-in-loop simulations on desktop; flight simulator tests and flight tests. Desktop simulation studies are primarily to validate candidate technologies of the IESVS components, fusion algorithms and physical properties of the environments of concern. Experiments on the flight simulator are meant to develop operational scenarios, study optimum human machine interface with different display strategies and study system integration issues. Simulator testing involves validation of a far more constrained set of models in the context of realistic operational scenarios flown by qualified pilots. Key features of the flight simulator from IESVS development perspective are that it gives high fidelity simulation of the cockpit environment, various flight scenarios, sensor visuals and weather conditions. To meet this demand a reconfigurable flight simulator is being setup at NAL with necessary flight displays, cockpit environment, sensors and weather simulation models.

It is expected that NextGen civil transport aircraft will be equipped with integrated modular avionics (IMA) architecture. Hence it is planned to integrate the IESVS with other avionics components in IMA architecture. Fig. 8 shows the proposed integration plan.

6. CONCLUSIONS

Integrated enhanced and synthetic vision system (IESVS) is currently the focus of advanced displays for avionics research to reduce accidents in commercial aviation which occur because of controlled flight into terrain (CFIT). NASA and other leading avionic research teams world over have carried out extensive research activities in IESVS and have evolved several best practice concepts for IESVS development. This paper highlights the technology and the design concept for realizing IESVS. Indigenous development of IESVS for the transport aircraft application has been initiated at National Aerospace Laboratories. As part of this effort, key operational requirements and the technologies required for realizing EVS for transport aircraft have been identified. A scaled down version of EVS hardware prototype with electro optical and infrared cameras has been developed and some field trials on a ground test vehicle are conducted. Functional and operational requirements, system requirements, and developmental road map for the development of IESVS for transport aircraft have been identified. Algorithms for image enhancement, registration, fusion, terrain integrity monitoring for synthetic data base and terrain elevation data and display requirements for IESVS have been identified. It is planned to carry out the development in a phased manner with human factor studies on a research simulator and then integrating the system onto the avionics suite for transport aircraft applications.

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